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# DETECTING CRACKS UNDER FERROUS FASTENERS USING THE NORTEC-30 EDDYSCAN FASTENER HOLE INSPECTION INSTRUMENT





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DEPARTMENT OF NATIONAL DEFENCE - CANADA

## Executive Summary

In 1992, a study using ultrasonic techniques to detect cracks under fastener heads in the CF116 upper wing skin was postponed by the Aerospace and Telecommunications Engineering Support Squadron (ATESS, formerly AMDU) because of poor repeatability. It was decided to institute a new probability of detection (POD) study to be conducted internationally in order to establish the capabilities and reliabilities of various non-destructive inspection techniques. The Canadian Forces' Quality Engineering Test Establishment (QETE) was tasked to manufacture test coupons reproducing the geometry of the CF116 upper wing skin golden triangle area with well-defined fatigue defects.

The fatigue cracks were generated in 0.258" diameter countersunk fastener holes drilled through 0.330" pieces of 7075-T651 aluminum alloy plate. These samples were then bolted to additional aluminum plates using alloy steel fasteners.

At AVRS, a Nortec-30 Eddyscan Fastener Hole Inspection Instrument was used to inspect these coupons to determine if it could detect the known fatigue cracks under the heads of the fasteners. It was found that magnetic fields caused by prior magnetization in a majority of ferrous fasteners resulted in large numbers of false indications. When non-ferrous or non-magnetized ferrous fasteners were used, the Nortec-30 was able to reliably detect relatively small flaws in the holes underneath the heads of these fasteners. Since the rotating coil eddy current technique is dependent upon the magnetic condition of the fastener, the Nortec-30 is not recommended for use with ferrous fastening systems.

# Detecting Cracks Under Ferrous Fasteners Using the Nortec-30 Eddyscan Fastener Hole Inspection Instrument

**by**

**R.W. Nolan and K.I. McRae**

## Introduction

In 1992, a study using ultrasonic techniques to detect cracks under fastener heads in the CF116 upper wing skin was postponed by the Aerospace and Telecommunications Engineering Support Squadron (ATESS, formerly AMDU) because of poor repeatability. It was decided to institute a new probability of detection (POD) study to be conducted internationally in order to establish the capabilities and reliabilities of various non-destructive inspection techniques. The Canadian Forces' Quality Engineering Test Establishment (QETE) was tasked to manufacture test coupons reproducing the geometry of the CF116 upper wing skin golden triangle area with well-defined fatigue defects (1).

Fatigue cracks were generated in holes drilled in samples of aluminum plate. These samples were then bolted to additional aluminum plates using ferrous fasteners. This report describes the results of measurement/inspection of the defects in these test coupons using a Nortec-30 Eddyscan Fastener Hole Inspection Instrument.

The Nortec-30 uses eddy current techniques to detect the size and position of flaws in holes under fasteners. A square wave pulse is applied to a coil at the centre of the rotating head of the instrument's scanner, inducing eddy currents in the test piece. Perturbations in the resulting magnetic field are then detected by a Hall Effect sensor rotating at the edge of the scanner which generates a signal dependent on the presence or absence of a flaw. If there are no defects, the signal is virtually a straight line. The presence of a flaw alters the magnetic field, producing a peak in the displayed signal which indicates both the amplitude and position of the defect. It is possible to determine the approximate depth of flaws by pre-setting three different timing gates on the instrument.

Details of the theory and operation of the Nortec-30 are given in its Operation Manual (2) and in Refs 3-5.

## Test Specimens and Procedures

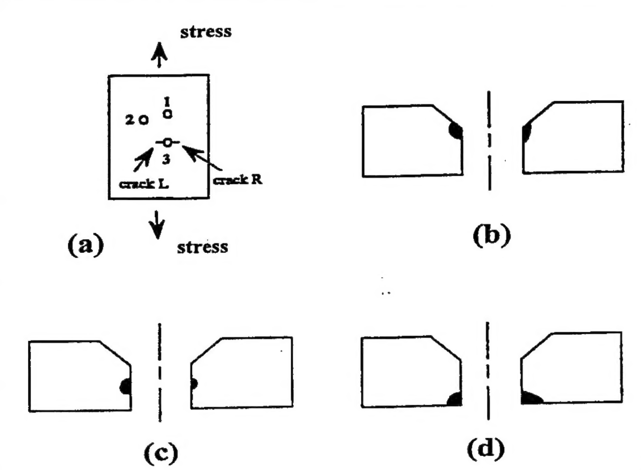


**Figure 1** - *Relative position of each type of flaw: ((b)-countersink, (c)-mid-bore, (d)-faying surface).*

Three 0.258" diameter countersunk fastener holes were drilled through 12x4x0.330" pieces of 7075-T651 aluminum alloy plate. Fatigue cracks were produced in most of these using electro-discharge machining and tensile loading. They were generated such that the propagation direction was normal to the principal tensile stress axis (Figure 1(a)). For a given coupon, the depth of each flaw was controlled such that it was generated either at the bottom of the countersink (CS), at the mid-bore (MB) or at the faying surface (FS) of each hole as shown in Figures 1 (b), (c) and (d), respectively. Several coupons were left unflawed. Eighty-two coupons (58 with cracks and 24 without cracks) were manufactured. Production methods and the exact location, size and geometry of each of the defects are described in detail using schematic diagrams in Ref 1.

Specimens of each type of test coupon were fastened to 4x4x0.25" aluminum plates using Hi-Lok HL21-8 alloy steel fasteners (0.25x7/8") and HL79-8 aluminum collars. A Nortec-30 Eddyscan Fastener Hole Inspection Instrument was then used for the measurement/inspection of the defects in several of these coupons.

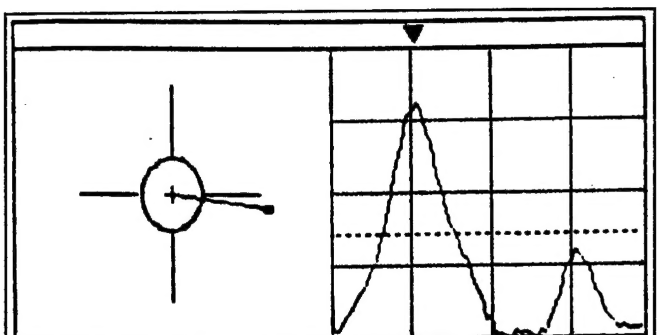

**Figure 2** - *Example of display generated by Nortec-30.*

The display generated by the Nortec-30 is illustrated in Figure 2. A simulated fastener hole target and centering crosshair ("+") are shown on the left side of the CRT screen and the active waveform of

the eddycurrent signal from the sensor is shown on the right. After the probe has been centered on a hole for approximately one second, the instrument switches automatically to capture the eddycurrent signal and freezes the display. The waveform generated when flaws are detected indicates their radial position and relative sizes and this information (for the largest flaw) is also displayed on the simulated target (illustrated by the straight line at 03:15). The vertical grid lines of the waveform display indicate radial positions of 12, 3, 6 and 9 o'clock, respectively. In this example a large flaw is indicated at approximately 3 o'clock, with a smaller one at 9 o'clock.

## Results and Discussion

After initializing the Nortec-30 as prescribed in its operation manual, holes in each of 16 test coupons were inspected. Although strong signals were recorded in most cases, cracks were rarely found in the expected 3/9 o'clock orientation. Often, only one of two cracks of approximately the same dimensions on opposite sides of a given hole was indicated. Many of the most powerful signals were obtained from the unflawed coupons.

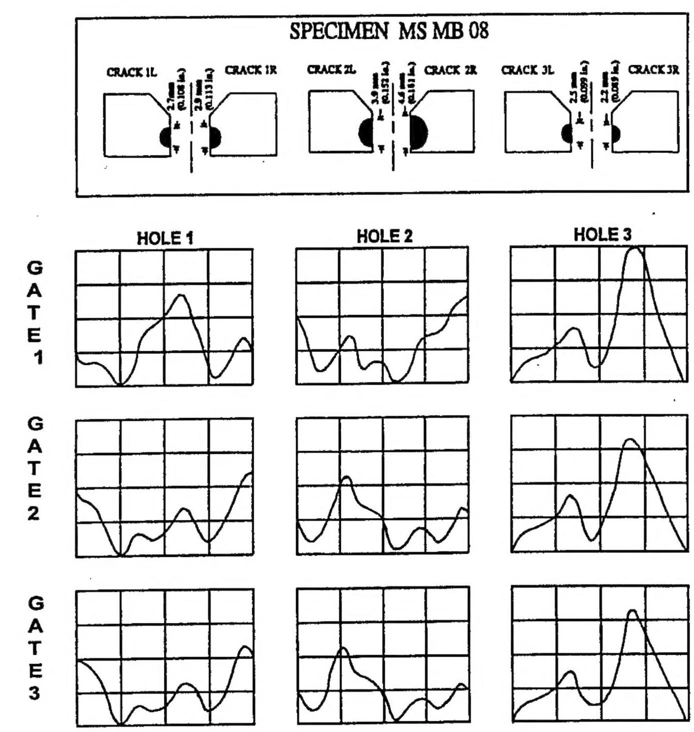


**Figure 3** - *Nortec-30 signals obtained from coupon MS MB 08.*

Figure 3 contains a schematic diagram showing the dimensions of the cracks in each of three holes in coupon MS MB 08. Tracings of the signal obtained from each hole in the specimen at each of three different Nortec-30 gate settings (depths) are illustrated underneath each schematic. The trace on each of the grids (three per hole) represents signal strength (0-100%) versus angular position around the circumference of the hole, with the origin being 12 o'clock, the first vertical line 3 o'clock, etc. It can be seen that although the cracks on opposite sides of a given hole are approximately the same size, a strong signal was normally obtained in only one location and that this location was most often not in the "correct" orientation. In this case, the weakest signal was obtained from the hole with the largest flaw and vice versa.

Figure 4 shows the Nortec-30 results obtained from each of three <u>unflawed</u> holes in coupon MS 11. All instrument settings were the same as for Fig. 3. It can be seen that cracks were indicated in each hole and that in most cases the signals obtained were stronger than those from the flawed specimen.

Liquid penetrant inspection of three different coupons after removal of the fasteners

SPECIMEN MS 11 (unflawed)

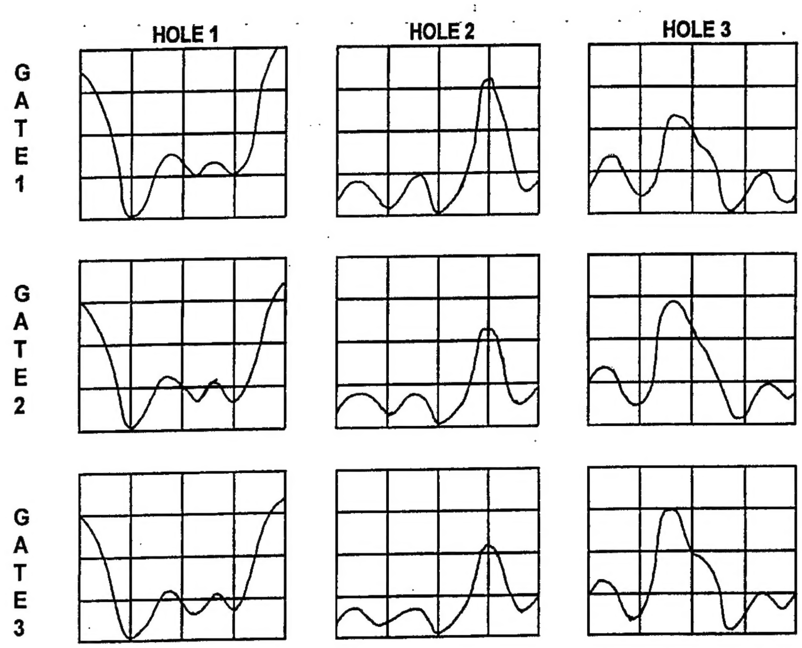


**Figure 4** - *Nortec-30 signals obtained from an <u>unflawed</u> coupon.*

confirmed that the cracks were indeed oriented as indicated in Ref 1. Subjectively, the relative sizes of the cracks also appeared to be as indicated.

It was noticed that flaw orientation/indication appeared to vary each time a fastener was removed and then returned to a hole. Since this technique depends on the measurement of magnetic signals, it was felt that random magnetization of the fasteners might be masking the perturbations caused by any flaws. Several bolts were purposely magnetized by leaving them in contact with a small hand-held magnet for several minutes. The top surface of the head of each of these was marked so that its angular position could be differentiated. These were then installed in holes in a coupon with relatively large cracks and in an unflawed coupon and the holes were inspected as the angular position of the fastener was varied. The strong signal obtained made it difficult to center the Nortec-30 scanner head over each hole. In each case, only one large "defect" was indicated, and its position varied with the orientation of the magnetized fastener. This result suggests that the signal resulting from the magnetic anomaly in the ferrous fastener overpowered any

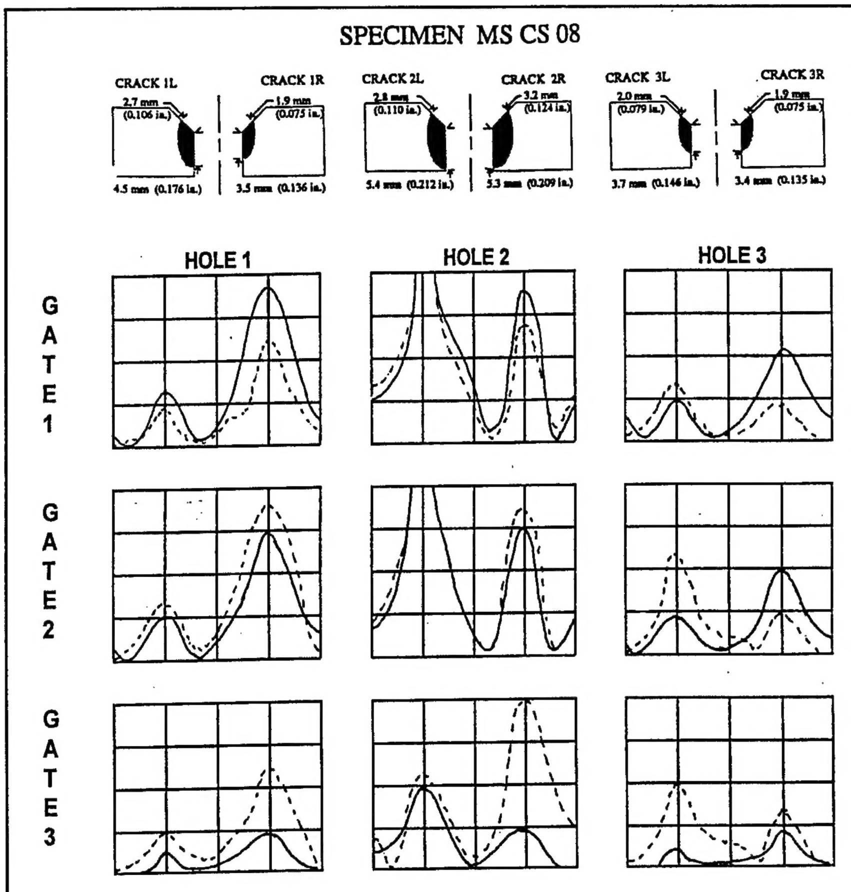


**Figure 5** - *Nortec-30 signals obtained using non-ferrous (solid lines) or non-magnetized fasteners (broken lines).*

signal caused by flaws in the sample. This effect was also probably responsible for the inconsistent results obtained with the initial test coupons.

The above experiment was repeated with the same flawed and unflawed test coupons but using titanium rather than ferrous fasteners. No defects were found in the unflawed sample. The signals obtained from the flawed coupon (MS CS 08) are illustrated in Fig 5 and were as expected. They show that the defects were located as indicated in Ref 1 (at 3 and 9 o'clock) and that signal strength was proportional to the relative size of the cracks.

Ferrous fasteners from a sample of approximately 100 were then selected at random, inserted into the holes in a non-flawed test coupon and scanned using the Nortec-30. The majority of these produced large false indications with only approximately 5% giving a zero or minimum signal, indicating that they were not magnetized. Three of these fasteners were then inserted into the holes in the flawed coupon MS CS 08 and scanned using the Nortec-30. The traces obtained are also shown in Fig 5 using broken lines. Again, the signals obtained were as expected, indicating the presence of flaws in the known locations.

During consultation with the manufacturer of the Nortec-30, Staveley Instruments Inc., it was suggested that the use of ferrous fasteners be avoided when attempting to measure defects with this instrument.

Difficulties with ferrous fasteners have been reported by only one other investigator. Hagemaier (6) evaluated the ability of four different eddy current devices to detect small cracks in holes in aluminum plate with both aluminum and steel fasteners. He found that the Nortec-30 detected noise from steel fasteners in unflawed holes when instrument gain was set at high levels. The instrument can easily detect small cracks (<0.040") under aluminum fasteners and can detect cracks between 0.050" and 0.075" under steel fasteners if a low signal-to-noise ratio is used. He reports that cracks <0.050" under steel fasteners are difficult to detect because instrument gain cannot be increased due to the increase in background noise. Spencer (4) concludes that the Nortec system is capable of detecting flaws > 0.060-0.070" with a high degree of confidence but neither he nor Chapman (5) specify what type of fasteners they used.

## Conclusions

It was found that the Nortec-30 Eddyscan Fastener Hole Inspection Instrument was capable of detecting relatively small artificially-produced fatigue cracks in holes in aluminum alloy plate underneath the heads of non-ferrous or non-magnetized ferrous fasteners. Magnetic fields caused by prior magnetization in a majority of ferrous fasteners resulted in large numbers of false indications. The application of the rotating coil eddy current technique for the inspection of cracks under ferrous fasteners is dependent upon the condition of the fastener. The Nortec-30, therefore, is not recommended for use with ferrous fastening systems.

## References

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6. D. Hagemaier, "Eddy Current Detection of Short Cracks Under Installed Fasteners", presented at 1995 ATA NDT Forum, Hartford, CT, September 1995

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A Nortec-30 Eddyscan Fastener Hole Inspection Instrument was used to detect known fatigue cracks under the heads of alloy steel fasteners installed in 0.258" diameter countersunk fastener holes drilled through 0.330" pieces of 7075-T651 aluminum alloy plate. It was found that magnetic fields caused by prior magnetization in a majority of ferrous fasteners resulted in large numbers of false indications. When non-ferrous or non-magnetized ferrous fasteners were used, the Nortec-30 was able to reliably detect relatively small flaws in the holes underneath the heads of these fasteners. Since the rotating coil eddy current technique is dependent upon the magnetic condition of the fastener, the Nortec-30 is not recommended for use with ferrous fastening systems.

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